

Measurement of periapical pressure created by occlusal loading

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Abstract

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Aim To develop an *in vitro* model in which the pressure in the periapical tissues can be measured during loading.

Methodology Extracted human maxillary central incisors were embedded in resin blocks that had physical characteristics similar to those of bone and periodontal ligament. Each tooth was loaded with 20, 40, 50, 60, 75, 85, 100, 200, 300 and 450 N vertical forces from the incisal edge of the crown on three consecutive occasions. A minute resistor embedded in the periapical space was used to detect apical pressure changes during

occlusal loading. The ratio of apical pressure changes (ΔP) to the loading force changes (ΔF) was calculated.

Results The periapical pressure detected was in direct proportion to the loading force. The mean value of $\Delta P/\Delta F$ was 5.994 kPa N⁻¹ (SD = 2.04).

Conclusions Direct proportionality was found between the coronal loading and the apical hydrostatic pressure. The $\Delta P/\Delta F$ ratio determined in this study makes it easier to estimate the apical hydrostatic pressure values during occlusal loading of single-rooted teeth. In this study, the apical pressure generated under occlusal loading was the same magnitude as that estimated with the finite element method.

Keywords: apical pressure, occlusal load.

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Introduction

For the evaluation of the sealing quality of root-canal filling materials and techniques, the fluid transport model has great physiological relevance. Biocompatibility tests involve not only the inflammatory or immunological reactions to test materials (both restorative and endodontic) but also the measurement of leakage between the materials tested and the hard tissues of teeth. The method with the highest clinical relevance is the fluid-filtration method, which was developed by Pashley *et al.* (1987) and has recently been introduced into endodontics. Amongst the various authors who have used the fluid-filtration method, there is considerable variation

in several aspects of the materials and methods (Pommel & Camps 2001). One of these is the pressure applied that varied from 1.5 to 136 kPa (Wu *et al.* 1994, Bates *et al.* 1996, Pommel & Camps 2001, Pommel *et al.* 2001). In order to compare the results from different studies, it is preferable for all studies to use the same pressure. Ideally, pressure should be expressed in fluid-transport measurements similar to those *in vivo* in the periapical tissues. Occlusal loading of the tooth increases the periapical hydrostatic pressure and can affect the seal between the filling material and the canal wall. The different pressures applied may result in different volumes of leakage. A significant increase in the leakage of root-canal fillings has been observed after repeated occlusal loading (Esber *et al.* 1998). However, the magnitude of the pressure occurring during occlusal loading is not known. This parameter may also have a negative influence on root-canal fillings. The apical pressure during chewing may also influence the healing of lesions or

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the development of external resorption and ankylosis. Early loading of traumatized teeth is a requirement of successful therapy to reduce the incidence of resorption and ankylosis. According to scientific examinations, the normal occlusal function is inevitable for rapid reconstruction of the damage caused by orthodontic forces (Terespolsky *et al.* 2002). Determining physiological pressure arising along the root of teeth may also have an importance.

In a 3D finite-element model, the pressure component of the apical stress in the periphery of the periodontal ligament (PDL) produced by loading the tooth was estimated to be 4 MPa when multiple forces (between 29 and 149 N) were applied to the occlusal surface of a mandibular molar (Kaewsuriyathumrong & Soma 1993). There are only a few reports that provide pressure values estimated at best (Darendeliler *et al.* 1992, Kaewsuriyathumrong & Soma 1993). However, measurements on natural human teeth may produce different values. A new model delivering pressure values of the periapical area makes it possible to control estimated data of the afore-mentioned studies and to perform clinical situations, for example, comparison of different root-end designs.

The aim of this study was to develop an *in vitro* model in which the pressure can be measured in the apical tissues during occlusal loading.

Materials and methods

Preparation of samples

Five extracted human maxillary central incisors with a patent foramen were used in this study. The teeth had been stored at 4 °C in 0.2% sodium-azide solution buffered with phosphate-buffered saline (PBS) at pH 7.2. At the start of the experiment, the roots were covered with a thin layer of wax, and a wax sphere (ϕ 10 mm) was attached to the apex. Prior to insertion into the wax sphere, a minute resistor for each tooth (0.3 mm $\times$ 0.5 mm $\times$ 1 mm; 20 k Ω 0402, mini Reel, Garden Grove, CA, USA) was calibrated and fitted with copper wires. The resistors were calibrated for the ratio of pressure and the voltage changes in a high-pressure gas chamber. A calibrated pressure transducer was used to determine the actual pressure value existing in the pressure chamber. The resistance changes (ΔR) to pressure changes were determined by the four resistances method based on Ohm's law. The four-wires method provides voltage data. The pressure values were calibrated by multiplying the actual voltage values by the

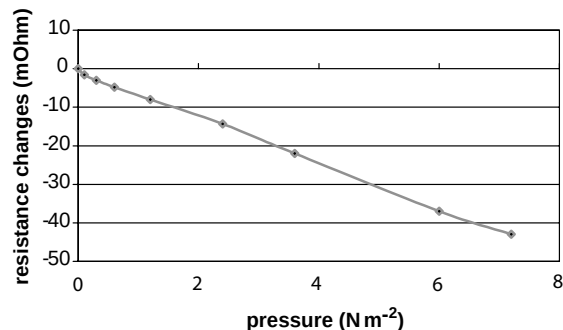


Figure 1 Calibration of resistors for the ratio of pressure and the resistance changes. The resistance of resistors decreases with increasing pressure in the pressure chamber. This makes it possible to use the resistor as a minute pressure sensor.

calibration coefficient of the pressure transducer ($25 \times 10^5 \text{ N/m}^2/\text{V } 10^{-1}$). The linearity of resistance changes was verified by measurement at different pressure values (Fig. 1). Each tooth was embedded in a resin box (5 cm long, 4 cm high, 2 cm wide) filled with light-polymerizing tray resin (Supertec, DMG GmbH, Hamburg, Germany). The resin was used to simulate the surrounding bone structure. The Young's modulus of the cured resin was measured using the bending method, and was 8 Gpa, which is in the range reported for bone (Breeding *et al.* 1995). Following the polymerization of the resin, the tooth was removed from the resin socket and the wax deposited in the simulated bone was melted and removed, using a stream pressure device (Plyno GV 6, Plyno S.A.S., Bologna, Italy). The apical space containing the minute resistor was filled with an interocclusal registration material (Silagum AV Quick Light, DMG GmbH, Hamburg, Germany). The same material was used to cover the entire root surface, and the tooth was inserted into its artificial alveolus with a gentle downward pressure. This impression material was used to simulate the apical soft tissue as well as the PDL. The Poisson's ratio of this material was 0.44. The physical characteristics of this material are similar to those of PDL (Breeding *et al.* 1995). A schematic drawing of the sample preparation is shown in Fig. 2.

Pressure measurements

Each tooth was loaded using a one-armed lever instrument with 20, 40, 50, 60, 75, 85, 100, 200, 300 and 450 N vertical forces at the incisal edge of the crown. The block of the embedded tooth was positioned so that

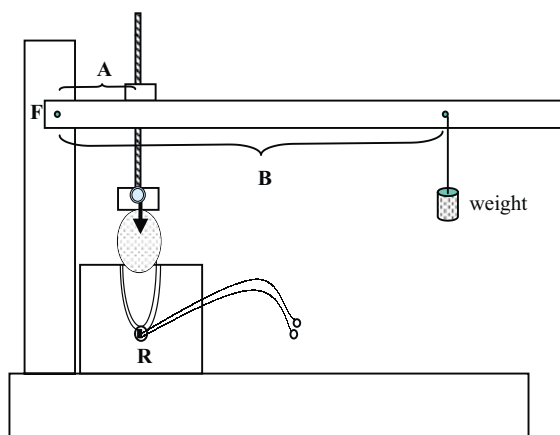


Figure 2 Schematic representation of the assembled test object. The arrangement is in fact a one-armed lever. The vertical load of the tooth can be controlled by the extent and position of the weights suspended on the arm. F means the fulcrum, FA distance means the lever arm and FB distance means the load arm. Attachment of the loading head to the leverage by nut and bolt makes it possible to set up the required height. A multiaxial joint turned into the loading head and a rubber bed between the leverage and the crown of the tooth provide a good mechanical contact as well as the uniaxial loading (arrow). Hydrostatic pressure is created in the apical lesion proportional to the loading. Changes in the resistance of the minute resistor embedded in the apical area of the tooth (R) under occlusal loading were measured as voltage changes in the resistance.

the vector of the force would be vertical and parallel to the axes of the tested tooth. The vertical directional loading was facilitated by a multiaxial joint that was formed into the loading head of the arm (Fig. 1). In order to provide a good mechanical contact and a uniform load to the uniaxial load, a rubber bed was used between the arm and the crown. Each loading measurement was repeated three consecutive times according to the applied forces. The apical pressure produced by vertical loading was detected by the minute resistor, which was connected to a resistance-measuring bridge and an amplifier. Instead of measuring the resistance changes directly, the voltage changes in the resistance were measured. The voltage changes were displayed on a multimeter (Multimeter 34401 A, Hewlett Packard, Kuala Lumpur, Malaysia). The mean value of the three voltage measurements produced by the same vertical loading was recorded. The mean values of the voltage changes were plotted as a function of the applied force. In the resulting curve (Fig. 3), the function is approximately linear. The slope of the approximated straight line

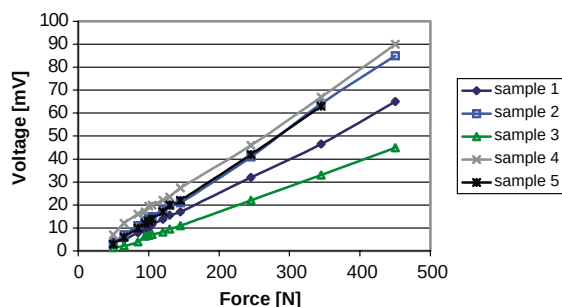


Figure 3 Correlation between the occlusal loading force and the measured voltage. Values of the measured voltage changes to the loading were entered into the co-ordinate system. Curves represent means of three data-points for one specimen. One tooth was cracked under a 350-N loading; therefore, its curve is shorter (sample 5). Slopes of the curves were calculated using trend lines (first degree functions), approximated to each curves. Slope values are shown in Table 1.

was calculated for each sample. The ratio of apical pressure change (ΔP) to loading force change (ΔF) was calculated using the following three additional parameters: calibration of resistor (C_R), constant of resistance measuring bridge and amplifier (C_E) and slope of the approximated straight line (S). The following equation was used:

$$\frac{\Delta P}{\Delta F} = \frac{S}{C_R} C_E$$

The mean and the standard deviation of $\Delta P/\Delta F$ values were determined.

Following the pressure measurement, the thickness of the simulated PDL was determined at the coronal, middle and apical levels. The samples were disassembled and the width of the artificial PDL was measured along the root surface at the apical, middle and coronal levels. The width measurements were made on four surfaces (mesial, buccal, distal and lingual) of each level, using an electronic digital caliper (Max Tool, San Dimas, CA, USA).

Results

In all five samples, the voltage changes were measured and the applied force produced a unitary curve of each sample as shown in Fig. 3. All of these curves could be characterized by a straight line, indicating that the apical pressure detected was proportional to the loading force.

Table 1 Slope values of the functions approximated to curves of measured voltages to occlusal loading

Sample number	Slope values	
1	0.1524	
2	0.2027	
3	0.1095	
4	0.2018	
5	0.2028	
Mean	0.1738	SD: 0.0419

Table 1 represents the slope values of the five curves belonging to the samples.

The mean value of $\Delta P/\Delta F$ calculated in the five samples was 5.994 kPa N⁻¹ (SD = 2.04).

The mean value of the thickness of artificial PDL was 0.18 mm (SD = 0.11).

Discussion

In the present study, a pressure testing apparatus was fabricated to provide measurements in simulated apical tissue of the pressure caused by occlusal loading. The model was designed to reproduce physiological conditions. Materials were selected to simulate bone and soft tissues because they had a modulus of elasticity similar to that of tissue. The Poisson's ratio of the interocclusal material used in this study, simulating PDL and the apical lesion, was 0.44, whilst the Poisson's ratio of the PDL *in vivo* is 0.45 (Kaewsuriyathumrong & Soma 1993). This similarity in the physical characteristics of the artificial tissue was not different from the natural tissues. However, some other differences between the natural and simulated systems may have influenced the results. The block of tray resin representing the alveolar bone cannot replicate the fine structure of bone with its outer compact and inner cancellous bones. Orientations of the collagen fibre bundles of the natural PDL and their suspension mechanism cannot replicate the model used in this study. Further limitation of this model is that it cannot simulate the variations in the physical characteristics of inflamed tissues. Materials with physical characteristics similar to those used in this study were also used by Breeding *et al.* (1995) in which stress distribution around an implant tooth-supported fixed partial denture was tested in a purpose-built testing apparatus. To date, it would appear that resistor-based pressure measurements have not been carried out previously in dental research. The calibration of pressure-sensitive resistors in a pressure chamber demonstrated that voltage changes in the resistors were in direct

proportion to the pressure applied; repeated measurements demonstrated the reliability of the method. The minute size of the resistors made it possible to embed them in apical material, simulating an apical lesion. The mode of embedment of the resistor into the elastic material simulating the apical lesion is pivotal. A resistor entirely incorporated into the elastic material can only register hydrostatic pressure (the uniform transfer of forces). Any contact between the resistor and hard tissues (root apex or artificial bone) would cause unwanted, uniaxial propagation of stresses towards the resistor. In such cases, the resistor would provide false values. Therefore, relatively, a high volume (10 mm diameter) of simulated apical lesion was used to avoid contact between the sensor and hard tissues.

In most studies 50, 75 and 100 N forces were used for occlusal loading (Southard *et al.* 1989, Holmes *et al.* 1996) probably because similar vertical forces have been measured during chewing movements in several *in vivo* studies (Proffit *et al.* 1983, Richter 1995). In the present study, the voltage changes proportional to the apical pressure (between 20 and 450 N) were determined as a function of the applied forces (Fig. 2). This curve produced a linear function between the voltage changes in the resistor and the coronal load applied. An equation was constructed for a ratio of apical pressure change to loading force ($\Delta P/\Delta F$), with a dimension of kPa N⁻¹. This ratio is useful for calculating the apical pressure produced by a given force within the observed range. For example, at 100 N loading, the apical pressure is 599.4 kPa, as in this study the mean $\Delta P/\Delta F$ value was 5.994 kPa N⁻¹. The pressure values recorded in this study cannot be compared with those estimated by the finite-element method (4 MPa) by Kaewsuriyathumrong & Soma (1993), as they tested a multirooted tooth (mandibular molar) that was loaded by multiple forces. The pattern of force distribution may be affected by the number as well as the shape of the roots. Darendeliler *et al.* (1992) calculated a 25 MPa compressive stress in the most apical radicular dentine under 450 N incisal loading of maxillary central incisors. They did not calculate stresses in the PDL under incisal loading, as they did not take into consideration the cementum as well as the PDL. If one accepts the observation by Kaewsuriyathumrong & Soma (1993) that the compressive stresses of the root surfaces are approximately twice as high as those of the periphery of the PDL, it can be concluded that the hydrostatic pressure in the periapical area of incisors tested by Darendeliler *et al.* (1992) is approximately 12.5 MPa. Using the ratio from this study, a 450-N incisal loading causes 2.69 MPa

pressure in the periapical area. Darendeliler *et al.* (1992) estimated the compressive stresses at the apical PDL to be four times higher than these measurements. However, this difference is not significant in view of various differences in the methods used. For example, in the study by Darendeliler *et al.* (1992), the applied load was not axial, but angled 26° lingually. In addition, there were differences in the parameters of the material used and the anatomical shapes of the samples. In the case of the calculations carried out by the finite-element method, it was assumed that the shape of the root tested had a rotational symmetry. In this study, however, the roots of the incisors tested were less regular in shape than those in the finite-element studies. This factor may also influence the pattern of stress distribution.

Assuming that the area of the incisal edge is 0.1 cm², the pressure on the edge is 10 MPa for a load of 100 N. The compressive stress at the apical PDL according to the present data is 599.4 kPa, which is much lower. A possible explanation is that the axial force dissipates towards the apical and lateral aspects of periradicular tissues. This concept is supported by Darendeliler *et al.* (1992). Using a 3D finite-element model, they found that the compressive stress was concentrated around the cervical portion of the central incisors. Asundi & Kishen (2000) reported a similar result during measurements using a strain-gauge and a photoelastic method.

Esber *et al.* (1998) subjected maxillary molars with filled root canals to masticatory cycles. The leakage was measured by means of dye penetration. The value of the dye penetration increased in proportion with the number of masticatory cycles. This observation suggests a significant effect of masticatory load on apical leakage. The magnitude of the pressure may also have an effect on apical leakage, but further research is necessary. On the basis of our results, the apical pressure in fluid-filtration model should be about 6.8 kPa. The pressure used in previous leakage studies (Wu *et al.* 1994, Bates *et al.* 1996, Pommel & Camps 2001, Pommel *et al.* 2001) varied from 1.5 to 136 kPa. A widely accepted pressure value in fluid-filtration studies will result in a better standardization of this method.

Conclusion

Direct proportionality was found between loading and apical hydrostatic pressure. The determined ($\Delta P/\Delta F$) value seems to be useful in determining apical hydrostatic pressure values during occlusal loading of single-rooted teeth.

Acknowledgements

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